

## Some Remarks on Extragalactic Globular Clusters

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### Abstract.

I comment (in a review fashion) on a few selected topics in the field of extragalactic globular clusters with strong emphasis on recent work. The topics are: bimodality in the colour distribution of cluster systems, young massive clusters, and the brightest old clusters. Globular cluster research, perhaps more than ever, has lead to important (at least to astronomers) progress and problems in galaxy structure and formation.

### 1. Introduction

#### **Eine einfache Anwendung des Newtonschen Gravitationsgesetzes auf die kugelförmigen Sternhaufen.**

Von  
**Albert Einstein-Berlin.**

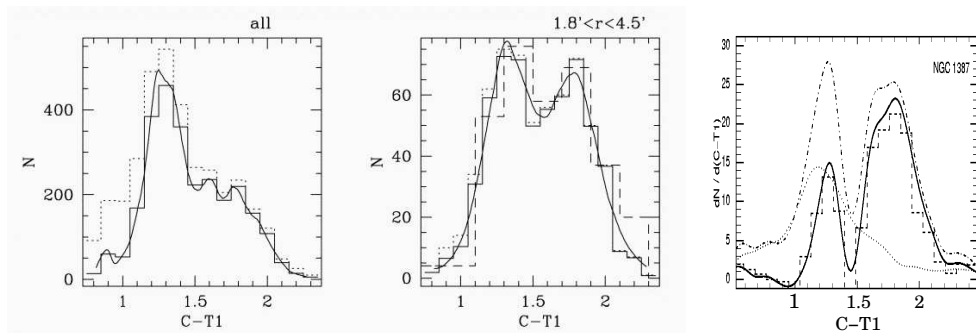
Es dürfte wohl kaum zu bezweifeln sein, daß das Newtonsche Gesetz über diejenigen Abstände hinaus, für die es verifiziert ist, extrapoliert werden darf. Dies Vertrauen wird auch durch die allgemeine Relativitätstheorie gestützt, die dem Newtonschen Gesetze eine rationelle Begründung

**Figure 1.** The heading of Einstein’s paper on M13. The title reads: A simple application of the Newtonian law of gravitation to globular star clusters.

Since 2005 is the Einstein-year, a talk on globular clusters can honour it by citing Einstein as a pioneer in globular cluster dynamics. In his paper on M13 (Einstein 1921) he concluded that the non-luminous mass contributes no higher order of magnitude to the total mass than does the luminous mass (Fig. 1). To my knowledge this has been

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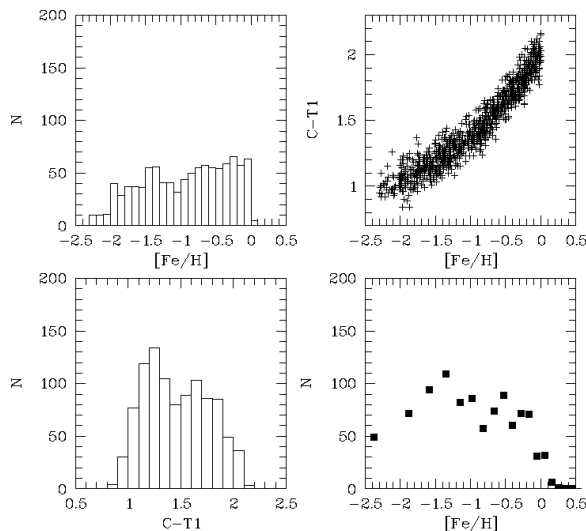
**Figure 2.** The colour distribution of the GCSs of NGC 1399 and NGC 1387 in the Washington system (Dirsch et al. 2003, Bassino et al. 2005). The left panel shows the entire system of NGC 1399, the middle panel its inner part. The solid line in the left panel is a smoothing of the solid histogram which displays the background corrected counts. The dotted line indicates the total counts. The same holds for the middle panel, except that the dashed line shows the counts of Ostrov et al. (1998). The right panel shows the GCS of NGC 1387, where the solid line is a smoothing of the dashed histogram, giving the background corrected counts. The dashed-dotted line means the smoothed total counts and the dotted line the background, which is dominated by the GCS of NGC 1399. The colour distributions are clearly bimodal, and that of NGC 1387 unique in its very large ratio of red to blue globular clusters.

Einstein’s only contact with globular clusters. As in other issues, his claim still holds. Globular clusters (GCs) may have the reputation of looking quite similar to each other, but they are a very inhomogeneous species regarding their intrinsic properties. In terms of mass, metallicity, age, density, they span orders of magnitudes. They are found in all types of galaxies, provided that the host galaxy’s mass is sufficient. Different from what was thought decades ago, GCs are not only survivors from the early Universe, but have also been formed regularly in galaxies and still form today.

The objective of this contribution is to highlight several recent topics in extragalactic GC research with some bias towards our own work. It is by no means exhaustive and will bravely face the usual fate, namely to be outdated soon. A more complete review is in preparation (Brodie & Strader 2006). The field is very extensive, ranging from stellar populations to cosmology, so only a few points can be illuminated. In the following I review/comment on these topics: colour bimodality in globular cluster systems (GCSs), young massive clusters, and the brightest old clusters.

## 2. Colour bimodality

There is no doubt that the GCSs of early-type galaxies exhibit substructure. The distinction between halo and bulge clusters with their differences in spatial distribution, chemical composition and kinematics is already familiar from the Galactic system. How-



**Figure 3.** This plot illustrates for the Washington system that a non-peaked metallicity distribution can result in a bimodal colour distribution. The upper left panel is the original metallicity distribution, the upper right panel the adopted metallicity-colour relation (Harris & Harris 2002) with a Gaussian scatter of 0.08 mag around the mean relation to simulate second parameters and photometric errors. The lower left panel shows the colour histogram, now bimodal, and the lower right panel the corresponding metallicity distribution.

ever, in the case of early-type galaxies, it has been the colour distribution which first indicated substructure. Ashman & Zepf (1992) were the first to investigate this. Because they identified two peaks in the colour distributions of the GCSs of NGC 5128 and NGC 4472 (Zepf & Ashman 1993), they termed them "bimodal" (in fact, they plot metallicities, not colours). A common scenario for the formation of giant ellipticals is through the merging of smaller galaxies. Linking bimodality with the merger scenario, they predicted the abundant formation of GCs in mergers, following Schweizer (1987). These newly formed GCs, presumably enriched, constitute the red (metal-rich) peak of the bimodal distribution. Later on, it has been found that indeed a lot of new GCs are formed in the star bursts which accompany merger events (see references in section 3). Bimodality could thus be understood as the sign of two epochs of GC formation. Other models with different prescriptions followed. Forbes et al. (1997) explained bimodality by having the metal-poor clusters formed "in situ". Côté et al. (2001) found the colour distributions most consistent with the accretion/infall of metal-poor clusters and the formation of metal-rich clusters in a dissipational collapse. Beasley et al. (2002) considered cluster formation within a semi-analytical model of galaxy formation and obtained bimodal metallicity distributions, the metal-poor clusters stemming from protogalactic fragments, and the metal-rich ones from subsequent gaseous mergers. More observations in the Washington system and in V-I (mainly based on HST data, Kundu & Whitmore

2001a, Kundu & Whitmore 2001b, Larsen et al. 2001) demonstrated that the majority of early-type galaxies, also including fainter galaxies, show bimodal colour distributions. In fact, *all* GCSs observed so far in the Washington system revealed bimodal distributions, while in V-I, perhaps due to the inferior metallicity resolution, a certain fraction remained unimodal or unclear. Interesting cases are NGC 524 or NGC 4365 (Larsen et al. 2001) which have quite rich GCSs, but appear unimodal. It would be interesting to observe these GCSs also in the Washington bands in order to see whether this is simply an effect of the photometric system.

However, one should note that in many cases, the term "bimodal" does not result from a clear-cut visual appearance in the colour distribution, but from a statistical analysis, often done with a KMM test.

Figure 2 shows the colour distributions in the Washington system of the GCSs of NGC 1399, the central giant elliptical in the Fornax cluster, and NGC 1387, a Fornax S0 galaxy near NGC 1399 (Dirsch et al. 2003, Bassino et al. 2005). To my knowledge this is the clearest bimodality seen in any galaxy. Being of quite low luminosity and an S0-galaxy, NGC 1387 is not a good candidate for supporting the merger scenario. However, the processes which produce S0s have, according to common wisdom to do, with interactions of galaxies, and the predominance of red clusters might have its explanation in the star burst which took place while NGC 1387 was transformed into an S0 galaxy. If also low-luminosity ellipticals have bimodal colour distributions, as seen e.g. in NGC 1427 by Forte et al. (2001) one may guess that all(!) GCSs have that property, as long as the full colour range is sufficiently sampled.

Is there a visible systematic relation between the peak locations and the properties of the host galaxy? Larsen et al. (2001), Kundu & Whitmore (2001a), and Kundu & Whitmore (2001b) agree that the red peak is redder for host galaxies of higher luminosity. This is not so clear for the blue peak. Larsen et al. (2001) also find the blue peak becoming bluer with decreasing galaxy luminosity and/or central velocity dispersion. Kundu & Whitmore, using partly the same data set, failed in uncovering such a relation. I shall come back to this shortly. In the Washington system, however, where the bimodalities show up much better than in V-I, such a correlation for the blue peak is less obvious (Bassino et al. 2005). This might have its basis in the fact that the HST data are much more homogeneous than ground based photometries from different telescopes, authors, reduction methods etc.. However, it also can mean that the colour of the blue peak is in fact (more or less) universal (of course, it should not be strictly universal: if the host luminosity is so low that the cluster system consists only of a handful of metal-poor clusters, it is plausible that the mean colour becomes bluer at some point).

An effect which argues for an almost universal blue peak and which has not yet been discussed before in the context of bimodalities is illustrated in Fig. 3. In the upper left panel a non-peaked distribution of cluster metallicities is shown (drawn from an exponential distribution). To transform it into colours we apply the relation of Harris & Harris (2002). However, at a given metallicity, the colour can vary due to second parameter effects and for real data also due to photometric errors. We simulate the combined effect by a Gaussian scatter with a dispersion of 0.08 mag. One also notes the non-linearity in the upper right panel. Then we rebin in colour (lower left panel). The striking blue peak

is a consequence of the scatter around a mean colour-metallicity relation in combination with the declining metallicity resolution at bluer colours. The lower right panel shows the rebinning in metallicity now assuming a unique metallicity-colour relation. The result differs significantly from the input distribution.

An intrinsically bimodal metallicity distribution plausibly gives a bimodal colour distribution, but our example shows that also a unimodal metallicity distribution may result in a bimodal colour distribution. The colour of the blue peak is uniform, depending on the (uniform) colour-metallicity relation and the scatter around the mean relation. Any non-linearity would help to create a blue peak. Strader et al. (2004) find that the mean colour of metal-poor clusters (they quote  $[\text{Fe}/\text{H}] < -1$ ) follows an extremely shallow relation like  $(V - I)_{\text{mean}} \sim -0.01 \cdot M_V$  ( $M_V$  being the host galaxy luminosity). They include intrinsically faint galaxies hosting only a few clusters, where the metallicity distribution is not fully sampled. Therefore their finding does not necessarily contradict a universal blue peak in the above sense. But Strader et al. (2005a) and Peng et al. (2005) found a similar slope among early-type galaxies in Virgo, so the blue peak does not seem to be strictly universal. Whether the described effect dominates the colour distribution is left to a deeper analysis, but at least it could be responsible for the shallowness of the above relation. Metallicity distribution and colour distribution might be less closely linked than previously thought. However, a colour distribution like that seen for NGC 1387 cannot be the result of non-linearity or second parameters, but probably indicates the disk and halo structure of an S0-galaxy, as has been found also for NGC 1380 (Kissler-Patig et al. 1997). Within a merger scenario, the resulting GCS is expected to be a composite of many different cluster formation processes: GC formation in the star bursts of the merger components, in tidal tails, the original clusters of the merger components, and late infall of clusters. The majority of clusters in early-type galaxies must have formed at high redshift: Strader et al. (2005b) found in their sample of spectroscopically derived ages and metallicities no clusters, whether blue or red, which are younger than about 10 Gyr. Moreover, no age difference between metal-poor and metal-rich clusters is visible within the uncertainties. The mere morphological phenomenon of colour bimodality as an indication of two and only two formation epochs should thus not be overinterpreted. Cluster colours provide first hints, but for the physically interesting substructure of a GCS to be revealed, one needs spectroscopic metallicities, ages, and kinematics.

When speaking about colour bimodality, one should also mention where it does *not* occur, namely among the brightest clusters in rich cluster systems (Dirsch et al. 2003, Harris et al. 2005). The absence of metal-poor objects among very massive clusters might be explained by massive progenitor clouds which are systematically more enriched than their less massive counterparts (Harris et al. 2005). Another (not necessarily competing) possibility is that this mass range is contaminated by tidally stripped dwarf galaxies whose nuclei now appear as globular clusters (compare also section 4).

### 3. Young massive clusters

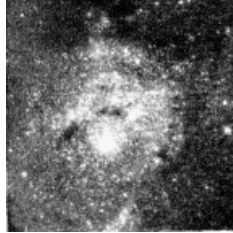
The classic view on GCs as representatives of the oldest stellar populations has experienced considerable modifications. Thirty years ago it was an irritating fact that the Magellanic Clouds host GC-like objects which are, however, much younger than the old Galactic GCs (e.g. van den Bergh 1975). Nowadays we know that the conditions for the formation of GCs were not exclusively realized in the early Universe but that GC formation is a regular feature of star formation processes in a variety of environments, the most spectacular ones being galaxy mergers (e.g. Whitmore et al. 1993, Whitmore & Schweizer 1995, de Grijs et al. 2003, Tran et al. 2003). The most massive young cluster known today is W3 in the merger galaxy NGC 7252 with an age of about 500 Myr and a mass of about  $8 \cdot 10^7 M_\odot$  (Maraston et al. 2004). It has an absolute magnitude of  $M_V = -16.3$  and thus rivals M32, the compact companion of the Andromeda galaxy. It still will have about  $M_V = -13$  when it is 12 Gyrs old, and thus may be a progenitor for "Ultracompact Dwarfs" (see the next section). Clusters often tend to form in complexes which for example are found in the Antenna galaxy (Whitmore et al. 1999). The simulations of Fellhauer & Kroupa (2002) predict a rapid merging of star cluster complexes, so consequently Fellhauer & Kroupa (2005) propose the merging of clusters as a possible formation scenario for W3.

Apparently, merger events provide the best conditions for forming massive clusters. If this is so one would expect to find intermediate-age globular clusters in galaxies which are known to be merger remnants. Nearby examples, where indeed intermediate-age clusters have been found, are Centaurus A, NGC 1316, and NGC 3921 (Peng et al. 2004, Goudfrooij et al. 2004, Schweizer et al. 2004). Intermediate-age clusters have also been detected photometrically in early-type galaxies which are not obvious merger remnants (Puzia et al. 2002, Hempel & Kissler-Patig 2004). The number of clusters formed in a merger event may plausibly depend much on its specific properties including the possibility that no clusters or only an insignificant number are formed. NGC 1052 shows some signatures of a recent merger with an associated star burst, but Pierce et al. (2005) did not find evidence for younger ages in their sample of 16 GCs.

Also starburst galaxies possess populations of young massive clusters. One example is NGC 1569 (Hunter et al. 2000) but there are many more.

However, the formation of globular clusters is not restricted to these relatively extreme environments. Larsen & Richtler (1999, 2000) performed the first systematic search among spiral galaxies for young luminous clusters. In their sample of 21 nearby face-on spirals, they found many. Introducing the parameter  $T_L$ , which measures the total light coming from the identified young clusters normalized to the light of the host galaxy, they showed that this parameter correlates best with the far-infrared luminosity of the host galaxy. This in turn is a measure for the star formation rate.

In comparison with the sample galaxies, the Milky Way's star formation rate is quite low, and the fact that Galactic massive young clusters are rare or even not existing, is therefore not surprising. However, one needs dynamical information in order to assess whether the luminous clusters found in galactic disks really are the young counterparts of

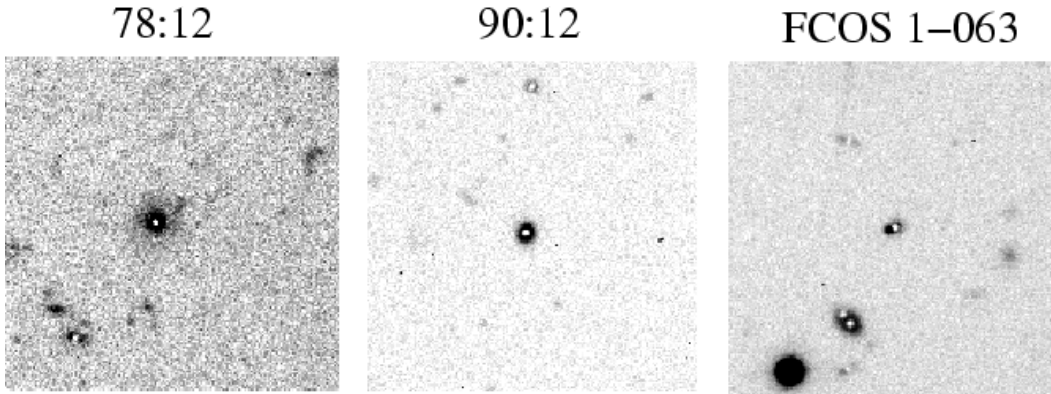


**Figure 4.** The image shows a "peculiar" complex in NGC 6946 (Larsen et al. 2002). A young massive cluster is located near the center of a region of enhanced star formation of almost circular shape. The diameter is about 600 pc. A number of smaller star clusters are found as well.

old GCs. Larsen & Richtler (2004) estimated virial masses for two bright clusters in M83, resulting in  $4.2 \cdot 10^5 M_{\odot}$  and  $5.2 \cdot 10^5 M_{\odot}$ , respectively. The cluster ages are about  $10^8$  and  $10^7$  years. The derived masses are consistent with "normal" stellar mass functions and show that these objects deserve the label "young globular clusters".

In the sample of Larsen & Richtler, NGC 6946 is worthy of particular note. Figure 4 shows an interesting cluster and its environment in this galaxy, investigated in detail by Elmegreen et al. (2000), Larsen et al. (2001), Larsen et al. (2002), and Efremov et al. (2002). The cluster is located near the center of a stellar complex with very high surface brightness and an approximately circular shape (diameter 600 pc) at a distance of 4.8 kpc from the center of NGC 6946. Its brightness is  $M_V = -13.2$  and its mass is estimated to be about  $5 \cdot 10^5 M_{\odot}$ . Other fainter clusters could be identified in this complex. Moreover, dust features are visible. It may be spherical, but a face-on disk structure with the massive cluster as the central object is plausible, regarding the thin disks even in large spiral galaxies. Although by far not as massive as W3, this concentrated occurrence of star clusters in a region with a high star formation rate is perhaps an example for the scenario suggested by Fellhauer & Kroupa (2002), leaving a cluster embedded in an extended envelope.

What does the correlation of star formation rate and efficient clustering mean? Could a high star formation rate be a trigger for cluster formation or do both result from the same physical conditions? It seems that the latter is the case. Cluster formation needs regions of high pressure (Elmegreen & Efremov 1997), the natural sites being the cores of giant molecular clouds. A high density of cold gas results in a high star formation efficiency and favours clustering (Geyer & Burkert 2001). In these regions the star formation rate is also high. Kravtsov & Gnedin (2005) simulate cluster formation in the context of hierarchical cosmologies and find a similar relation between the efficiency of forming massive clusters and the star formation rate as found by Larsen & Richtler. In their model, the interpretation simply is the above. However, the conditions which lead to a large reservoir of cold, dense gas might be different in different galaxy types. Billett et al. (2002) searched for massive clusters in dwarf irregular galaxies. The main result is that dwarf galaxies do not follow the trends observed for spirals. Billett et al. explain the correlation between star formation rate and clustering found for large spirals by correla-



**Figure 5.** PSF-subtracted images for some resolved objects near NGC 1399 (Richtler et al. 2005).

tions between star formation rate, maximum cluster mass, column density, and pressure in combination with statistical effects. They suggest that GC formation in dwarf galaxies occurs under different circumstances than in spiral galaxies, triggered by large scale flows in the absence of shear. The most massive clusters in dwarf galaxies are statistically not expected, but probably need unique conditions. It therefore seems that a general high star formation rate is a necessary condition for GC formation, but not a sufficient one.

#### 4. The brightest old clusters

The long history of research on the brightest cluster in the Galactic system,  $\omega$  Centauri, has yet not converged towards a commonly accepted picture. The last two years saw some surprising discoveries (see Piotto et al. 2005 and references therein). One could cautiously say that a scenario in which  $\omega$  Centauri has formerly been the nucleus of a dwarf galaxies which has fallen into the Milky Way and has been tidally stripped, is perhaps the most promising working hypothesis (e.g. Hilker & Richtler 2000). Other models are, however, not ruled out. For example, Fellhauer & Kroupa (2003) discuss the formation of super-star clusters in an ancient star burst, which subsequently merged to form  $\omega$  Centauri.

If it is already that difficult to understand a Galactic GC with all possibilities of detailed investigation, it is not surprising that unfamiliar objects in external galaxies are even more difficult to understand. Hilker et al. (1999), searching for new members of the Fornax galaxy cluster, "discovered" two GC-like objects with radial velocities placing them into the Fornax cluster, but with magnitudes brighter than any GC known until then. In fact, the brighter one was resolved and labelled "compact dwarf elliptical" earlier by Minniti et al. (1998). They already noted that these objects could be the stripped nuclei of dwarf galaxies, as was suggested before by the simulations of Bassino

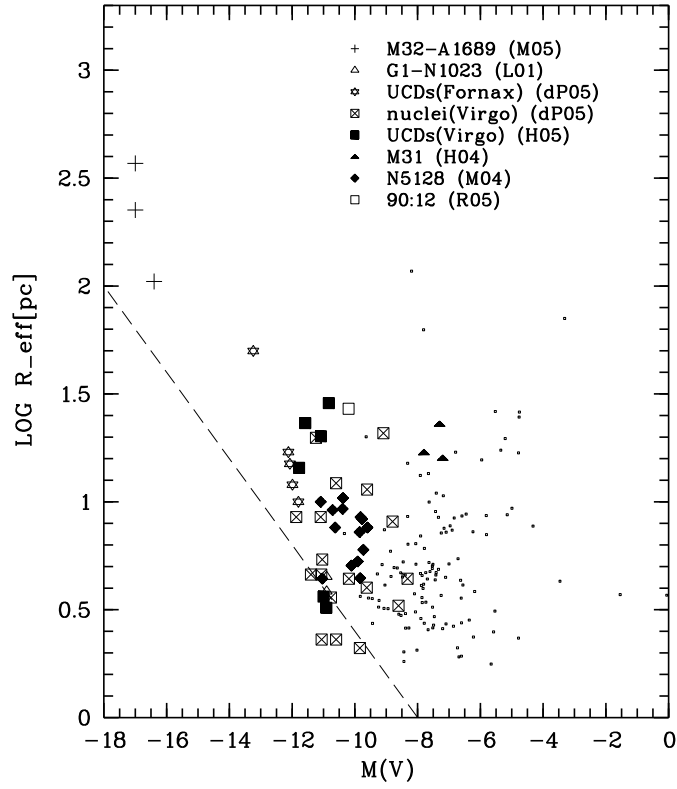


et al. (1994). Drinkwater et al. (2000) and Phillips et al. (2001) found three more in the course of the 2dF survey and introduced the designation "Ultra Compact Dwarfs (UCDs)". These objects have absolute magnitudes in the range  $-12.1 < M_V < -13.4$ . HST observations and VLT spectroscopy permitted to derive structural parameters and M/L-ratios (Drinkwater 2003). Their half-light radii are in the range 15-30 pc, much larger than those of most GCs. M/L<sub>V</sub>-values lie between 2 and 4, not strikingly high for GCs. Metallicities are not well known. For one object, UCD 2, spectral line indices are available (Mieske et al. 2004) and their metallicity of -0.6 dex agrees well with that derived from its Washington colour (Richtler et al. 2005), when an old age is assumed.

All these objects have been found within 30 arcmin from NGC 1399. This is still within the area covered by the GCS of NGC 1399, which extends to over 40 arcmin (Bassino et al. 2006). No object of this kind has been found in the general Fornax field, which already suggests that the close distance to NGC 1399 plays an important role.

The UCDs populate a previously deserted area in the  $M_V - r_{eff}$ -plane. Meanwhile, more objects with similar characteristics have been found in the Fornax cluster, but also in other environments. Unfortunately, HST-images for Fornax objects exist only for the 7 UCDs, so structural parameters remain uncertain, although it is possible to resolve larger GC clusters also on ground based images in good seeing. Richtler et al. (2005) present a short list of "noteworthy" objects which have been found in the course of a spectroscopic survey of the NGC 1399 GCS (Richtler et al. 2004, Dirsch et al. 2004). Figure 5 shows a selection of such objects. On VLT images, some of them are well resolved and one (90:12) has an effective radius of 27 pc, rivaling those of UCDs, but an absolute magnitude of "only"  $M_V \approx -10.3$ . Another one (78:12) has a large, faint halo with a radius of at least 200 pc, which will probably even be larger on deeper images. Such an object has never been seen before, although "extra-tidal" light has been found as well around GCs in NGC 5128 (Harris et al. 2002). Since all these objects have been found on only two FORS2 fields (in total 42 arcmin<sup>2</sup>), one expects many more to be discovered in a complete census of the system. Mieske et al. (2004) identify more bright GC-like objects, which still await HST- or ground based high resolution imaging. Meanwhile, a lot of interesting objects have been found in other galaxies as well. Since there is no space for a thorough discussion, I mention briefly the most recent ones. Huxor et al. (2004) found extraordinarily extended clusters in the halo of M31 with absolute magnitudes around  $M_V \approx -7.2$  and half-light radii of about 30 pc. Mieske et al. (2005) discovered twins to M32 in the galaxy cluster Abell 1689, leaving M32 no longer lonesome in its properties. Hasegan et al. (2005), in the course of the ACS Virgo survey, discovered bright GC-like objects around M87 and other Virgo galaxies, but with half-light radii resembling those of the UCDs in the Fornax cluster. Martini & Ho (2004) present a list of 14 bright clusters in NGC 5128 with measured velocity dispersions and structural parameters (see also Gómez et al. 2005). The reader is also referred to the recent results of the ACS Virgo survey (Jordan et al. 2005), which we cannot discuss here.

Is any combination of luminosity and concentration possible? Figure 6 plots (following Huxor et al. (2004) absolute magnitudes and effective radii for GCs and GC-like objects, including Galactic GCs, dwarf galaxy nuclei, and M32-like objects. Identifications and references are given in the figure and figure caption. Population properties like ages and



**Figure 6.** Absolute visual magnitudes vs. effective radii (pc) for a number of objects. The dashed line is a line of constant surface brightness within the effective radius ( $\mu_V = 14.8/\text{arcsec}^2$ ). References: dots (Galactic GCs): Harris 1996; M05: Mieske et al. 2005; L01: Larsen 2001; dP05: de Propris et al. 2005; H05: Haşegan et al. 2005; H04: Huxor et al. 2004; M04: Martini & Ho 2004; R05: Richtler et al. 2005.

metallicities are not known for most of the newly discovered objects, so normalisation to, say, solar abundance and an old age is not possible. However, it seems that the indicated dashed line (line of constant surface brightness within an effective radius) constitutes some sort of limit to the surface brightness, corresponding to  $\mu_V = 14.8/\text{arcsec}^2$ . Until now, the brightest UCD in Fornax (UCD 3) seems to be unique; the others finding their counterparts also around M87 in the Virgo cluster. While UCD 3 seems to be particular,

the others might well be understood as the brightest GCs in the NGC 1399 system. In Fig. 6 there is only a small morphological gap (if any) between UCDs and "real" GCs (whatever they are) and one may expect that the space towards fainter magnitudes, but equally large effective radii, will be filled once a complete census of NGC 1399 GCs will be available. Bekki et al. (2001, 2003) simulated the stripping of nucleated dwarf galaxies in the potential of a giant galaxy ("galaxy threshing"). These simulations support the scenario in which UCDs emerge from nucleated dwarfs. However, the nuclei themselves are not greatly affected in the simulations so one should expect to find nuclei with similar properties as the UCDs. De Propris et al. (2005) compare structural properties of the nuclei of Virgo dwarf galaxies with those of UCDs and conclude that most dwarf nuclei are too faint and too concentrated to be progenitors for UCDs. As can be seen in Fig. 6, only two or three nuclei could be candidates for fainter UCDs. The brightest one, UCD 3, shows a surface brightness profile different from the others, which are well fit by King profiles (Drinkwater et al. 2003). An additional exponential halo with a scale length of 60 pc is required to obtain a good fit. Adopting an old age, UCD3 must have been about 4 mag brighter at the time of its formation. This combination of brightness and concentration is extremely rare, but a plausible intermediate-age counterpart is W3 in NGC 7252 (Maraston et al. 2004).

There are more arguments in favour and against dwarf galaxies as progenitors for UCDs. An interesting idea is from Mieske et al. (2004) who expect a dynamical difference between "normal" GCs and objects which are the result of "galaxy threshing". Since the stripping process relies on elongated orbits and small perigalactic radii (Bassino 1994, Bekki et al. 2001) the velocity dispersion of UCDs should be lower than that of GCs because one selects a radially biased subpopulation and one expects to find UCDs far from their pericenters. The number of UCDs is admittedly small for dynamical analyses. However, from the sample of Mieske et al. it appears that the brightest GCs have indeed a (marginally) smaller velocity dispersion.

Perhaps a deeper insight into the nature of UCDs results from the work of Hasegan et al. (2005). They present a list of bright and relatively compact objects around M87 and other galaxies in the Virgo cluster, which they name "Dwarf-Globular Transition Objects (DGTOs)". For six of them, internal velocity dispersions from Keck spectroscopy are available. Two of them are extremely compact and have structural properties similar to G1 in M31 or Larsen's object in NGC 1023 (Larsen 2001). Their  $M/L_V$ -ratios are high (about 3) but still consistent with old, metal-rich GCs. Three of the other four, however, have  $6 < M/L_V < 9.4$ . Interestingly, the object with the largest effective radius again has  $M/L_V \approx 3$ . Hasegan et al. propose that the high  $M/L_V$ -ratios are due to a high dark matter content which is the distinguishing property between UCDs and "normal" GCs. The dark matter halo would then be the dark matter debris of a stripped dwarf galaxy. If this was true, none of the Fornax objects would be real UCDs in the sense of Hasegan et al., since the  $M/L$ -values measured by Drinkwater (2003) are all plausibly consistent with stellar populations.

However, since the measured velocity dispersion essentially is the central velocity dispersion, the mass profile of UCDs with a dark matter halo must be closely following the light profile to have a dark matter dominated central region. This again would be

strange, because stripping of dwarf galaxies works most effectively with a flat dark matter core (Bekki et al. 2003). Another possibility is a central black hole, which would have to be rather massive to increase the M/L-ratio by a factor of 2. Baumgardt et al. (2005) show that a black hole can puff up the core of its hosting cluster quite considerably. Einstein’s finding for M13 (see the introduction) perhaps is still relevant for distinguishing globular clusters from UCDs.

It is also interesting to note that many of the brightest globular clusters, including W3, have quite high ellipticities (e.g. Larsen 2001), while the UCDs and dwarf galaxy nuclei appear more spherical. If the ellipticity is due to rotation (which is not known), one could think of it as a consequence of angular momentum conservation in the merging of smaller subunits, but the simulations of Fellhauer & Kroupa (2002) reveal quite spherical objects as a result of cluster merging.

However, the example of W3 shows that very massive clusters can form without invoking a scenario with infalling donor galaxies and it remains open to what degree infalling dwarf galaxies can shape the appearance of a GC system.

## 5. Concluding remarks

The field of GC research, of which a few topics have been presented here, is as exciting as ever. One cannot yet claim that the formation of globular clusters and their relation to their host galaxies are well understood, neither does it constitute a total mystery. Globular clusters may even have formed in different ways as entire objects or by coagulation of smaller units. Their potential for understanding galaxy formation and evolution is just on the verge of being exploited. The determination of ages, metallicities, internal dynamics, and kinematic and dynamical properties of cluster systems requires lots of work. However, it is fun by itself and promises deep insights into the evolution of structure. Einstein’s notion that M13 does not host large amounts of dark matter touched already upon one of the fundamentals of structure formation and today even appears more relevant than 85 years ago.

## 6. Acknowledgements

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